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## EXPERIENCE OF DEVELOPING AN INTEGRATED NONDESTRUCTIVE ASSAY SYSTEM

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### ABSTRACT

A consortium of national laboratories is collaborating with the Savannah River Plant to develop an integrated system of state-of-the-art nondestructive assay (NDA) instrumentation to provide nuclear materials accounting and process control information for a new plutonium scrap recovery facility. Individual microcomputer-based instruments report assay results to an instrument control computer (ICC). The ICC, in turn, is part of a larger computer network that includes computers that perform process control and nuclear materials accounting functions. The experience in developing the integrated NDA system, the design, and the testing are discussed.

### I. INTRODUCTION

A new plutonium scrap recovery facility has been constructed at the Savannah River Plant (SRP). Los Alamos National Laboratory collaborated with SRP to define and develop an integrated system of modern, automated non-destructive assay (NDA) instrumentation that will provide nuclear materials accounting and process monitoring information to the operators of this facility. The goal is to provide an accountability system capable of drawing frequent material balances with minimum reliance on laboratory measurements of analytical samples.

This state-of-the-art instrumentation has been designed and fabricated by Los Alamos National Laboratory, Lawrence Livermore National Laboratory (LLNL), Mound Laboratories, and Savannah River Laboratory. Los Alamos serves as system coordinator, combining the individual components into an integrated package with the 10 NDA instruments reporting to a central instrument control computer (ICC). The ICC, in turn, is integrated into a facility computer network that includes other computers dedicated to process control and nuclear materials accounting functions. The three computers that compose this network have dedicated functions but exchange relevant information through a

Digital Equipment Corporation network (DECNET) communications link to optimize the simultaneous performance of all three functions. The integrated system is illustrated schematically in Fig. 1. The details of the system design have been reported in previous publications.<sup>1,2</sup>

The system has undergone extensive development for more than 3 years. The equipment has been shipped to and installed at SRP. When the facility initiates plutonium processing, Los Alamos and the other national laboratories will assist in performing the initial calibration and check-out of all NDA instrumentation. Implementing this integrated system in a process environment represents a major step in realizing the full capabilities of modern NDA instrumentation.

In developing such a system, we have learned many things and have had to constantly remind ourselves to keep the system simple; it is sufficiently complicated with 10 instruments working as a system. This paper describes our experience in developing such an integrated system so that other facilities considering such a system may benefit from this experience.

### II. DESIGN CRITERIA

#### A. Modular Approach

When the SRP personnel contacted us concerning the development of such a system, we welcomed the project because of its unique challenge: to build an integrated system in an actual chemical processing facility. Because this experience was new, we could not anticipate all the problems we might encounter or the time development might require. We had approximately 3 years to build and develop the system. Several of the state-of-the-art NDA systems took 2 years to develop and test. The tight schedule mandated that only proven techniques or simple extrapolations of proven techniques could be used, and that as much of the development as possible should be done in parallel. Table I



to check the message length and a check sum to check the longitudinal sum of the message characters. All information is transferred in ASCII characters so that a nonintelligent terminal can be used for debugging. This feature is useful in the instruments' integration and testing phases.

### C. Master/Slave Relationship

There are six or more microcomputers reporting to the ICC (DEC VAX-750) computer in this project. During the project's design phase, it is crucial to decide which computer will be the master and initiate the communication and which will be the slave and listen to the communication. We decided that the microcomputers should be the master and the ICC should be the slave for the following reason: The microcomputer has limited memory, and most of the NDA systems are pushing the limit of the computer memory before adding the task of listening to the ICC; the ICC computer is a much more powerful computer (VAX) and has sufficient memory to take on the task of waiting for communications from the microcomputers. All communications are to be initiated by the NDA instruments; except when acknowledging receipt of information or sending requested information, the central computer is ready to receive messages.

Several suggestions have been made for bi-directional communication, with the ICC and the microcomputer both able to initiate a communication; this process would significantly increase the system's complexity with very little gain in the system's versatility.

## III. DESIGN FEATURES

The design goal of this project is that the individual instruments can be operated in a stand-alone mode. This setup anticipates the situation in which the ICC computer is not functional; the facility still can process material using manual entry. It was also the design goal of the project to ensure that the system can be easily maintained both from the hardware and software points of view. Another design objective is that the instruments should have measurement control (MC) features.

### A. Hardware Standardisation

In a large project such as this one where the hardware cost exceeds a million dollars, standardisation is crucial. Standardisation has several other advantages such as reducing the number of spare parts needed for back-up and simplifying the training of personnel in maintaining and operating the NDA instruments. Hardware components have been standardized as much as practicable.

Considerable effort has been devoted to the details of hardware configuration. For example, a standard  $\mu$ -11 backplane configuration is used throughout for all the instruments; identical vector and address are used for each of the devices interfaced with the computer. An example of the standard back plane layout is shown in Table II. Another example of the hardware standardisation is the electronic components. Figure 2 shows the electronic racks for all the NDA instruments in this project provided by the four laboratories; they look identical except for the logo identifying the instrument.

### B. Software Commonality

From the beginning of the project, it was agreed that DEC software should be used because all four laboratories involved had experience writing DEC software. A lot of time and discussion have been devoted to the issue of using RT (single-user DEC software) vs RSX (multiuser DEC software). The RT operating system was selected for several reasons: it is simpler; it is easier to write the device driver for a single-user system and to generate the system software; and most of the developers are more familiar with RT software.

From a facility operations viewpoint, the most important software is the interface between the individual NDA instruments and the operators performing the assay. All instruments are operated from terminals and have standardized operator/instrument dialogue. For example, the 'A' command on one instrument will start an assay, as in any other instrument; the 'MB' command will initiate a MC bias run on any instrument. This standardisation reduces the complexity of operator training as well as potential confusion because the same operator will likely perform assays on several instruments.

The operator/instrument interaction is based on our experience with installed instruments at the Los Alamos Plutonium Facility. Over a 7-year period, each instrument installed has featured further refinements of the operator/instrument interaction with the goal of developing a truly user-friendly system.

There is the question of what to do with the assay or MC data when the ICC is not functioning. Each of the NDA modules is designed so that it can archive assay results and MC data up to 7 days (100 records each). In each of the NDA systems, there are two log files: one for assay results and one for MC results. These two files serve dual purposes: they are used for archival results, and they can be used by the supervisor to examine previous data from the terminal. It is assumed that the ICC will be repaired within 7 days. During this period the assay results can be manually entered into the accountability computer. When the ICC is repaired and on line again, the archived assay

TABLE 11  
BACKPLANE AND PERIPHERAL DEVICE INFORMATION FOR MICRO-11

1	QUAD	u-11 CPU	M8199
2	QUAD	u-11 memory	M8067
3	QUAD	Cambridge 8673V	
4	DUAL	DLV-11J	DUAL DBV-11
5	QUAD	RDS0/RXS1 u-11 disk	M8839
6	EMPTY SLOT		
7	EMPTY SLOT		
8	EMPTY SLOT		

Device	Address	Vector	Interf. Board	Baud	Connect
System console	177560 176500	60 100	u-11 CPU port A0 u-11 CPU port A1	100	T1703
Series 30 MCA	176100	120	Cambridge 8673V	57.6k	
User term #1	176540	140	DLV11-J ch0	100	T1703 (LOCAL)
User term #2	176550	150	DLV11-J ch1	100	T1703 (FCC)
VAX comm	176560	160	DLV11-J ch2	2400	7 data bits, 8th even parity, 1 start, 1 stop
ISR-11	176570	170	DLV11-J ch3	100	Pin-to-pin cable
Monitor	167770	70	DBV11		2 bit LOCAL 1 bit FCC
RDS1, RXS0	172150	154	RQDX1		



Fig. 2. Electronic racks during the integral testing phase.

and MC results will be sent to the ICC automatically. The ICC will archive data for 1 month, after which the data can be copied onto removable disks for permanent storage.

#### C. MC

The ICC is mandated by DOE requirements. It is important to have a well-thought-out MC program early in the project so that the measurement systems can incorporate MC into the instrument design. The MC program for the various instruments is based on that developed for the Los Alamos Plutonium Facility.<sup>4</sup> This MC program has been used at Los Alamos since 1979, and substantial operational experience has been accumulated.

The MCs are divided into two levels. Level 1 MC is performed on the individual NDA instrument at which a few simple statistical checks are performed. These checks, performed at

regular intervals, include a bias check, a precision check, and a background check. Diagnostic checks are also incorporated. For gamma-ray systems, the diagnostic checks consist of a detector resolution check and zero and gain stabilizer checks. For neutron coincidence systems, the diagnostic check would include a totals-to- accidentals test.

Level 2 MC is performed at the ICC level. At this level, all NDA systems will have control charts to monitor the trends of the bias-check and precision-check data. In addition, Page's test for trends of the measurement process can be performed at the ICC. Because all the instruments are on-line to the ICC, every MC run will be archived at the ICC, which then can accumulate realistic performance data on each of the NDA systems. A detailed description of the MC program can be found in Ref. 5.

#### IV. TESTING

In a complex project, testing is crucial. In this project, three levels of testing have been performed: individual module, communications, and system.

Because each of the NDA instruments is a module, performance testing on each module is conducted at the four participating laboratories. Each NDA instrument was tested for the different assay modes (assay, background, MC bias, and MC precision). The accuracy and the precision of the instrument are tested according to the specifications. The archival capability of each module is also examined. Finally, the reliability of the module is tested.

The unique phase of this project is the integral staging. The primary purpose of this phase was to check the communications between various computers and to verify the ICC software during the operation of the NDA instruments. To accomplish this initiative, all the NDA instruments from all the laboratories were shipped and installed at Los Alamos. After each instrument was tested successfully in the stand-alone mode, it was brought on-line with the ICC. Communication tests were then performed by exercising each of the NDA instruments in the various assay modes mentioned earlier.

Next, the Feed Assay Room instruments (plutonium solid isotopics, calorimeter, and the feed coincidence counter) were exercised together to verify that they could provide a plutonium value for the input of the process. Then, the Sample Assay Room (SAR) instruments (turbidimeter, densitometer, x-ray fluorescence, gamma pulse-height analyzer, and low-resolution assay instrument) were exercised together. Samples that would require a process measurement and/or accountability measurement were routed through the SAR by different regime modes representing different assay sequences. For each assay

sequence, the communications between the ICC and the accountability and process control computers were checked. Both normal and abnormal operations (ICC down) were tested to simulate realistic operational conditions, including operator error.

#### V. CONCLUSION

The design, development, system integration, training, and installation phases of the NDA system have been completed; the only remaining task is the *in situ* calibration. In this project, we have had to constantly strive to simplify the system without compromising the capability of the system. Throughout this period, a spirit of camaraderie developed among the four laboratories and SRP personnel. Because of this dedicated team effort, this project was successfully completed. Figure 3 shows the Los Alamos team in front of some of the assay systems during the integral testing phase.



Fig. 3. Los Alamos team in front of some of the assay systems during the integral testing.

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